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plying the method of storing linotype bars and using them as needed, for example, in the cumulation decade by decade of the Royal Society's International Catalog. This work could be organized for the future in three years and printing of the first two decades of the twentieth century finished in five or less. I am less sure that it will come than I am confident of the future provision in the way of books. But if and when the key to the record does exist, then no budding scientist may fail of confidence in his start, of the help in his labors as they go on year by year which comes from knowing what has been done and what is being done by his fellows. We shall have them ready at hand—not alone the record in print of human efforts to comprehend the universe, but also such an effective and useful key to that record that we may reverse the old saying, and affirm he who reads may run.

WM. WARNER BISHOP

MAY 26, 1922

THE DEPLETION OF SOILS BY CHEMICAL DENUDATION

THE rate of chemical denudation of soil and rock material has been of vital interest to geologists and soil scientists. The geologist has been interested in an attempt to establish a unit of time for estimating the age of the ocean, the time periods of geologic processes and incidentally the time periods of the life of man, animals and other forms of life on the globe. He has been ably assisted by hydrographers and oceanographers. The soil scientist has been interested in relation to time measurements of soil productivity and of methods to be taken to prolong the life and the endurance of the soil for the agricultural needs of the people.

Unfortunately the vast amount of information that has been collected has been based mainly upon the translocation of material in true solution, disregarding all material in colloidal solution. The results of the methods used have shown surprisingly little silica, alumina and iron lost from the soil in comparison, for instance, with the amount of potash lost. In fact, the soil scientists have assumed that the three first named elements,

which form by far the larger proportion of the soil, remain in the soil because of their slight solubility. There has been a lack of evidence of any considerable loss of these through solution.

The hydrographers have determined, from the average composition of the soluble salts carried to the sea, that SiO_2 constitutes 8.60 per cent., Al_2O_3 and Fe_2O_3 together constitute 0.64 per cent. and K_2O 2.13 per cent. This gives a ratio of one part of potash to 4.4 parts of silica, alumina and iron. As the ratio of potash to silica, alumina and iron in igneous and in shale rocks is about 1 : 25, there is an apparent selective loss of potash; that is, the loss of potash is relatively much greater than the loss of the main soil constituents. From this fact, together with the fact that plants appear to have the same selective power of absorption of potash in much greater proportion than of the original proportion of the main soil constituents, soil scientists have taken a very pessimistic view of the length of time the soil will remain fit for agricultural use.

Opinions have been advanced by some that our most productive soils will only last for one hundred and fifty years or so without replacement, because of this selective loss of plant food material due to their greater solubility and assuming further that the silica, alumina and iron are removed in very small proportions from the soil because of their relative insolubility. Such is briefly an outline of the situation up to a short time ago.

If silica, alumina and iron are removed from the soil in proportion to the loss of the so-called more soluble salts the losses could not be determined by chemical analysis any more than the removal of a cartload of soil would affect the chemical composition of the material that remains. Recent investigations of the soil colloids by this bureau suggest that this may be actually what takes place. It would appear that, in the breaking down of the silicates to a point where the potash goes into solution, silica, alumina and iron also go into solution in the same proportion as they bear to the potash content in the original material. There is, however, this very important difference which has not heretofore been recognized or properly appreciated and that is that the solution of

silica, alumina and iron is a colloidal solution as distinguished from the true solution of the so-called soluble elements.

The methods devised for separating colloids from soils for analysis and study, and the methods for the determination of the amount of colloids in soils have apparently opened up a new and vast field of research, the results of which will undoubtedly throw a broader light upon the subject of chemical denudation.

In my paper on "The Origin of Soil Colloids and Reason for the Existence of This State of Matter," published in *SCIENCE*, December 30, 1921, I called attention to the fact that in the mechanical analysis of soils under microscopical control practically the smallest particle of matter is .0001 mm. I advanced the opinion that complex silicates of such small diameters contain relatively so few molecules that when brought into contact with water the bombardment of the water molecules shatters the mineral particles, the electrolytes going into true solution and the silica, alumina and iron going into colloidal solution, the colloids thus formed reabsorbing much or all of the electrolytes, which puts these electrolytes themselves in large part into a colloidal state.

It is difficult to conceive how the electrolytes can be dissolved out of silicates at ordinary temperatures and pressures without conceiving that the whole thing breaks down into a dissolved mass. In fact, direct evidence of this is to be found in the dry grinding of silicates in the ball mill. If this fine ground material is brought into contact with water, soluble salts go into solution as determined by conductivity or chemical test, and at the same time there is released a relatively large amount of colloidal material. What the exact ratio is between the potash, for example, which has been released from the silicate rock, and the silica, alumina and iron in the resulting colloids formed has not been determined.

Soil colloids in suspension of a gram to the liter give the appearance under the ultra microscope of minute droplets immiscible with the surrounding water capable of indefinite suspension. In larger concentrations the droplets appear to coalesce, forming a jelly-like mass which settles to the bottom of the vessel. These

soil colloids have a distribution equilibrium, however, between the colloid and the surrounding water, involving silica, potash and other electrolytes to a notable extent, but affecting the iron and alumina only to an inconsiderable extent.

We have a general idea of this distribution equivalent in the case of analyses which have been made of the truly soluble material that passes through the Pasteur-Chamberlain filter in comparison with the colloidal material which remains on the outside of the filter tubes. The colloidal material of the Miami silty clay loam soil collected on the outside of the tubes on a strictly water-free basis carries 54.15 per cent. SiO_2 , 28.03 per cent. Al_2O_3 and 13.39 per cent. Fe_2O_3 . These together add up 95.57 per cent. of colloidal material. The content of K_2O is 2.89 per cent., giving a ratio of potash to silica, alumina and iron of 1 : 33. In the dissolved salts which have passed through the filter tube there is 10.4 per cent. SiO_2 , 2.9 per cent. Al_2O_3 and Fe_2O_3 , making 13.3 per cent., while the K_2O content is 8.1 per cent., giving a ratio of 1 : 1.6. The salts of the river waters of the United States contain on the average 8.60 per cent. of SiO_2 , .64 per cent. of Al_2O_3 and Fe_2O_3 , making a total of 9.24 per cent., while the K_2O content is 2.13 per cent., giving a ratio of 1 : 4.4.

The average analysis of igneous rocks as given by Washington on a strictly water-free basis shows 60.14 per cent. of SiO_2 , 16.32 per cent. of Al_2O_3 and 7.84 per cent. of Fe_2O_3 and FeO calculated to Fe_2O_3 . This makes 84.30 per cent., while the K_2O content is 3.27 per cent. This gives a ratio of potash to silica, alumina and iron of 1 : 25.8, as compared with the ratio of 1 : 33 in the case of the Miami soil colloid as above. The composition and ratio of potash to silica, alumina and iron in shale rocks is nearly identical with the igneous rocks.

The average composition of deep marine sediments ("red clay") on a water-free basis, excluding sea salts and shells, shows according to Steiger 54.48 per cent. SiO_2 , 17.15 per cent. Al_2O_3 and 10.36 per cent. of Fe_2O_3 and FeO calculated to Fe_2O_3 . This makes a total of 81.99 per cent., while the K_2O content is 3.07

per cent. This gives a ratio of potash to silica, alumina and iron of 1 : 26.7 or very nearly the ratio in the igneous rocks. The "terrigeneous clay" of the deep marine sediments has a rather larger content of SiO_2 and a somewhat smaller content of K_2O , giving a ratio of 1 : 36.4.

The average composition of the soil colloids shows somewhat less SiO_2 than is contained in igneous rocks but considerably more Al_2O_3 and Fe_2O_3 , indicating probably that much of the quartz from the disintegrating rock remains as such in the soil. On the other hand, it is seen that the marine sediments have gained in SiO_2 over the soil colloid for which we can offer at present no explanation.

An examination of the Miami silty clay loam soil shows the following very interesting figures. If we assume a weight of 3,500,000 pounds per acre foot, the composition on a water-free basis with 81.11 per cent. of SiO_2 shows 2,838,850 pounds of SiO_2 per acre; Al_2O_3 at 10.46 per cent. gives 366,100 pounds per acre; Fe_2O_3 at 2.80 per cent. gives 98,000 pounds per acre, while K_2O at 2.27 per cent. gives 79,450 pounds per acre. The amount of soil colloid at 19.3 per cent. gives 675,500 pounds of colloid per acre foot. The SiO_2 content of this colloid amounts to 365,780 pounds, the Al_2O_3 189,340 pounds, and the Fe_2O_3 90,449 pounds, while the K_2O content of the colloid is 19,522 pounds per acre.

The total soluble salts of the Miami silty clay loam soil collected after passing through the Pasteur-Chamberlain filter, after treatment of one part of soil to five parts of water, amounts to 60 parts per million of the soil. The SiO_2 in soluble form in this soil collected under these conditions is therefore 22.43 pounds per acre and the Al_2O_3 and Fe_2O_3 6.16 pounds, while the K_2O is 27.16 pounds per acre.

This bureau has determined from observation of river waters the presence of colloidal material but has made no analysis to determine the amount or composition of this colloid. Unfortunately, in all of the river analyses that have been made the amount of silica, alumina and iron in colloidal solution owing to the lack of methods has not been determined and has not been included in the evidence presented of chemical denudation. It seems likely that the colloids carried by the rivers approximate in composition the soil colloid and arguing from

the figures above given pertaining to the Miami silty clay loam soil the 2.13 per cent. of K_2O and the 9.24 per cent. of silica, alumina and iron as reported for the average river water gives only one part of the story. If the ratio of 1 : 1.6 of potash to silica, alumina and iron of the soluble salts is changed to the ratio of 1 : 33 as in the colloidal solution, then in addition to the soluble potash, silica, alumina and iron as reported in the river water analyses, we will have a colloidal solution carrying, in its dry parts, 2.89 per cent. of potash, 54.15 per cent. SiO_2 , 28.03 per cent. Al_2O_3 and 13.39 per cent. Fe_2O_3 .

The total additional amount of potash in the colloidal matter carried by the rivers, as compared with the total amount of potash in true solution, and the total amounts of SiO_2 , Al_2O_3 and Fe_2O_3 carried in this colloidal matter, as compared with the amounts carried in true solution, can not be determined without further investigations and further determinations of the material carried by the river water. If we knew the amount of soluble material in the river water, the amount of colloidally dissolved material and the amount of unaltered rock fragments there would still be one item which would make comparison difficult and would be seemingly difficult to evaluate, and that is the amount of CO_2 that enters from the air and from decomposing organic matter, which would combine with some of the constituents noticeably with lime, either in the soil or in the river water. It seems likely, however, from the consideration of the facts given that this would be a small factor.

Until we evaluate all these factors and particularly until we determine the actual loss through chemical denudation of silica, alumina, iron, potash and other electrolytes in the colloidal state carried by the rivers, we are in no position to even speculate as to whether chemical erosion is a selective process which might change the chemical composition of the soil or whether materials leave the soil in about their original ratios which would not change materially the chemical composition of the soil upon which water has acted.

MILTON WHITNEY

BUREAU OF SOILS,
U. S. DEPT. OF AGRICULTURE,
WASHINGTON, D. C.